Neuromorphic Computing: Is It Worth It?

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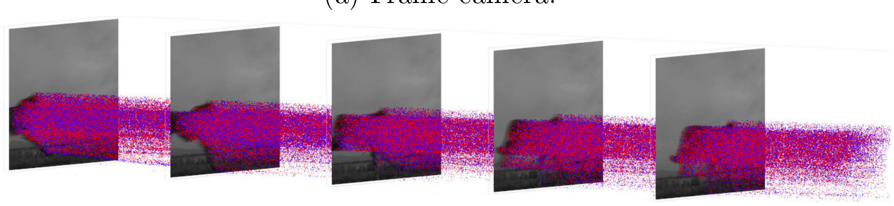
Traditional computer hardware faces challenges with the increasing scale and complexity of machine intelligence requiring higher performance per watt efficiency and lower latency. Neuromorphic processors offer an alternative with asynchronous event-based parallelism and efficient mobile robot solutions. These processors are designed to run the spiking neural networks (SNNs) which emulate the learning and computing principles of biological neurons. In contrast to the conventional artificial neural networks (ANNs), the SNNs have more biologically plausible features and encode the information not by the intensity of the signal, but by a series of binary events, also called spikes, and the relative time between them.

The paper [1] achieves a vision-based landing with a conventional, frame-based sensor using the SNN. Even though only the vertical motion of the drone was controlled with the SNN, it presents the very first embedded application of a neuromorphic chip in a flying robot.

The SNN is an appropriate solution for simultaneous localization and mapping (SLAM), as it requires energy efficiency. Reference [2] demonstrates that the SNN architecture running on a neuromorphic processor can achieve comparable accuracy to traditional processors while consuming significantly less power. Specifically, [2] presents a neuromorphic chip-based solution for the SLAM problem in one dimension, which does not depend on the external ground truth information.

Along with neuromorphic processors, there are also bio-inspired neuromorphic vision sensors, namely, event cameras [3]. Event cameras differ from conventional frame cameras: instead of capturing frames, event cameras detect changes in the scene and generate a stream of per-pixel events that reports these changes in real-time. An event is generated when a pixel in the camera's sensor detects a change in brightness above a certain threshold, and the event contains information about the location, intensity, and time of the change (Figure 1). Event cameras offer attractive features compared with traditional cameras: higher temporal resolution, much higher dynamic range, lower power consumption, and high pixel bandwidth resulting in reduced motion blur.

(a) Frame camera.



(b) Event camera.

Figure 1: Comparison of the data produced by an event camera and a conventional camera. Image adapted from Wikipedia, https://wikipedia.org/wiki/Event_camera.

Despite their promising features in challenging environments, event cameras cannot be directly applied to the existing SLAM algorithms. As it is stated in [4], some methods adopt conventional frame-based methods on an alternative event representation, while others combine event data with other data sources to achieve better performance. Another approach is to directly process event data using filter-based methods. For instance, [5] introduced the first hybrid pipeline that fuses events, standard frames, and inertial measurements to produce accurate and robust state estimation. On the other hand, [6] presented a real-time six-degree-of-freedom visual odometry approach that solely relies on data from an event-based sensor, representing a significant breakthrough.

The inherent asynchrony of neuron spikes in a neuromorphic processor makes it an ideal computational partner for an event camera. Unlike traditional architectures, neuromorphic processors can directly process events produced by the event camera without conversion, offering better data-processing locality, and resulting in low-power and low-latency computer vision systems. That is why, [7] introduced a neuromorphic controller that outperforms the state-of-the-art controllers in high-speed control due to the synergy between the high update rates of the neuromorphic chip and the event camera. Finally, [8] presented the first fully neuromorphic vision-to-control pipeline for a freely flying drone, which can accurately follow various ego-motion setpoints, and perform hovering, landing, and lateral maneuvers, even under the constant yaw rate.

In conclusion, event-based vision and neuromorphic computing hold great worth in transforming machine intelligence. The development of state-of-the-art hardware and software has opened up new possibilities for autonomous systems and has led to exciting advancements in the field of robotics. With their exceptional energy efficiency and precision, the SNNs within neuromorphic computing offer a promising path for achieving fully autonomous systems and real-time neuromorphic control of robots. However, the sparse, noisy, and motion-variant characteristics of event data present challenges that require further investigation to fully realize the potential advantages of event cameras and enhance event-based SLAM systems. Ongoing research and development in academia and industry are expected to yield breakthroughs in more reliable learning algorithms and efficient implementations, leading to autonomous systems operating with confidence in complex environments.

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